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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report discusses the history of requirement for and structure of the Integrated Flexible Welding System (IFWS), one of the projects in the Naval Sea Systems Command's (NAVSEA) Integrated Robotics Program. This project sponsored by the Navy Manufacturing Technology (MT) Office, is intended to develop a flexible, adaptive gas metal arc welding (GMAW) capability for making high quality, cost effective welds on small batch or single workpiece items in a shipyard environment. The IFWS concept has resulted in the development of separately developed modules which could stand
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20. Abstract (continued)

alone if necessary; however the intent is to integrate them into a system tailored to satisfy Navy unique manufacturing and repair needs. Modules discussed in the report include the Robotic Adaptive Welding System (RAWS) the 3D- Weld Seam Tracking System (3D WSTS), and the Global Vision System (GVS). Typing all the components together is the Intelligent Communications Interface (ICI), a hierarchical control architecture linking knowledge-based design, planning and control activities to the modules performing the work. The report closes with a statement of the integration plan to be followed when implementing the IFWS.

INTEGRATED FLEXIBLE WELDING SYSTEM

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INTEGRATED FLEXIBLE WELDING SYSTEM

Within the family of more than fifty projects which constitute the corpus of the Integrated Robotics Program of the Naval Sea Systems Command (NAVSEA) is one which is so reflective of the Navy's needs, so demanding in terms of its technological requirements, and so forward looking in the manner in which it seeks to integrate advances in robotics componentry, that it is considered to be the best measure of recent efforts to introduce such technology to a Navy whose principal involvement has heretofore been basically limited to weaponry. This centerpiece project is the Integrated Flexible Welding System (IFWS), and will be described in the following pages both in terms of its separately developed supporting subsystems as well as its final integrated form.

The rapidly evolving field of robotics offers tremendous potential for improving numerous functions associated with the construction, maintenance, and operation of ships and weapons systems. The goal of the IFWS is to provide an adaptive robotic welding capability for use in construction and repair, and to develop technological insights that are transferable to other applications when eventually the confluence of needs and available technology become apparent to a wider Navy constituency. In pursuing this goal, the approach has been to develop the required technology in a modular fashion, combining proven modules into interim configurations for near-term payoff as we continue the development of advanced modules for integration into the ultimate system. In other words, it is

expected to effectively reduce the cost of the total system by generating payoff from the early implementation of subsystems just as soon as they are tested and evaluated, while gathering in the process that essential real-world feedback from the user community.

THE NEED

Shipbuilding is by nature one of the most complicated engineering and construction endeavors undertaken by man. Large structural components with limited physical access are pre-outfitted with sophisticated propulsion, support, and weapons systems to form complex subassemblies which are then joined together to make up the vessel. The low volumes and unstructured environments associated with this manufacturing process make the application of robotics technology very difficult. The workpieces themselves are massive in comparison to conventional assembly line scenarios, and dimensional uncertainties contribute further to the problem. In outdoor assembly areas, structural subassemblies and components can grow several inches in length from expansion due to heat of the sun alone, and react as well to thermal distortions caused by the welding and cutting processes employed. Ships are essentially built as single entities, and the time required for manually programming a robot to perform a given function generates costs that cannot be amortized for lack of a production run over a long series of identical parts. Accordingly, the shipbuilding industry has been unable to capitalize on benefits that other industries have enjoyed through the employment of industrial robots in assembly line operation.

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It is important to clearly understand this fact and to realize that much of the work being done by industry to automate manufacturing and assembly scenarios in pursuit of the "factory of the future" regrettably has little applicability to the building of ships and other Navy needs. Thus both Navy and private shipyards are confronted with unique requirements that the commercial robotic industry cannot be expected to address for some time. Those are the facts that have provided the impetus for the IFWS, and dictated its objective: to develop a flexible, adaptive gas metal arc welding (GMAW) capability for making high quality, cost effective welds on small batch or single workpiece items in a shipyard environment. Yesterday, that objective was technologically unrealistic; today it is a complex challenge; tomorrow it is achievable!

EVOLUTION

To understand the complexity of the challenge the IFWS project is confronting, it is helpful to accept the premise that the marriage of robotics technology with the welding process produces a situation where the value of the sum exceeds the total of the values for the individual components. Welding has long been considered an art, accompanied by the associated extensive hands-on training and exhaustive finished product testing that an art form requires. Robotics technology, especially that which incorporates CAD input and process control feedback, has advanced to the point where an industrial workcell can reliably and consistently perform a specified set of tasks of ever increasing complexity. The robotic welding workcell thus becomes the

vehicle to transform welding from an art to an engineering science capable of yielding a predictable finished product. In fact, the prognosis appears strong that it may even be possible to specify that window in which key process parameters must fall to ensure a quality weld. If these same parameters can then be monitored in real time, and be certified as having not deviated from this range, it may be that much of the expensive post-weld non-destructive testing can be eliminated in the certification of certain classes of non-critical welds.

In light of these premises, it was to be expected that robotic welding applications would appear as strong potential candidates for employing new technology in attempts to increase productivity and improve quality. It was not surprising, therefore, to discover in mid-1983 that as many as ten independently conceived and separately pursued welding-related robotic developments were underway within NAVSEA. In the same time frame, the Office of Robotics and Autonomous Systems (SEA 90G), with the NAVSEA Robotics Council serving as its support arm, had been established to coordinate the Robotics Program for the Naval Sea Systems Command. At the request of the Navy Manufacturing Technology (MT) Office, and in keeping with the precept of avoiding unwanted redundancy through the promotion of technology transfer, this team conducted a thorough review of several of these projects. The resulting recommendation was to organize all ongoing work to the support of two major thrust areas, adaptive gas metal arc and laser welding. Efforts in laser metalworking were well orchestrated in an MT project entitled Laser Articulating Robotic System (LARS), managed for NAVSEA by

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Henry Watson of Penn State and under contract with MTS Systems Corporation. In the GMAW area, there was a clear neeɑ for an effective integration effort that could build upon the technology of the work in progress and provide long term goals and objectives consistent with the true needs of the shipyard user communities. A recommendation to this effect was endorsed and the IFWS was established as a full-fledged endeavor early in 1985.

The development of the IFWS concept proceeded in keeping with the application pull theory of project formulation. The NAVSEA approach in pursuing robotic solutions to long standing operational needs has been to determine just what technical components and capabilities would be necessary to implement a robotic solution for a proposed application. These technological needs are then categorized as follows: 1) those that exist as state of the art, 2) those under development by universities, industry, or the government, and 3) those that are unique to the application and not being addressed. Hardware and software subcomponents of the IFWS are subjected to this examination criteria to ensure that procurements are executed in the most resource efficient manner available to the Navy.

SYSTEM DEVELOPMENT

The evolutionary and modular development approach employed in IFWS adheres closely to the SEA 90G concept of centralized policy direction fɔr projects subject to decentralized execution and management. The system development was structured to support the achievement of the conceptualized goal to implement a truly integrated robotic GMAW workcell with adaptive weld process

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control, three dimensional seam tracking, and a global workcell vision capability, all enhanced through the implementation of task specific expert systems.

The performing organizations for the appropriate component developments were identified and selected according to their specific areas of expertise. By definition, this approach required modularity and concurrency in subsystem development, two beneficial side effects permitting expedient near-term results supported by the flexibility to prosper from long-range technological innovations. Moreover, this approach provides an assurance that the IFWS can be modernized and upgraded in a continuing evolutionary fashion as improvements in the supporting technologies come to pass. This philosophy seeks to substantially lower the risk of having a very expensive development effort result in a static system highly susceptible to early obsolescence because it could not be progressively improved on a module by module basis.

Architecture

As shown in Figure 1, the IFWS system architecture clearly depicts this modular approach. Serving as the schematic representation of the finished product, it provides a means to guide all supporting efforts towards an effective integration. The concept calls for the interfacing of various sensor modules as well as the robot and weld process control modules to a local area network (LAN) through the Intelligent Communications Interface (ICI) developed by the Naval Ocean Systems Center (NOSC). Various expert systems are employed at the top of the
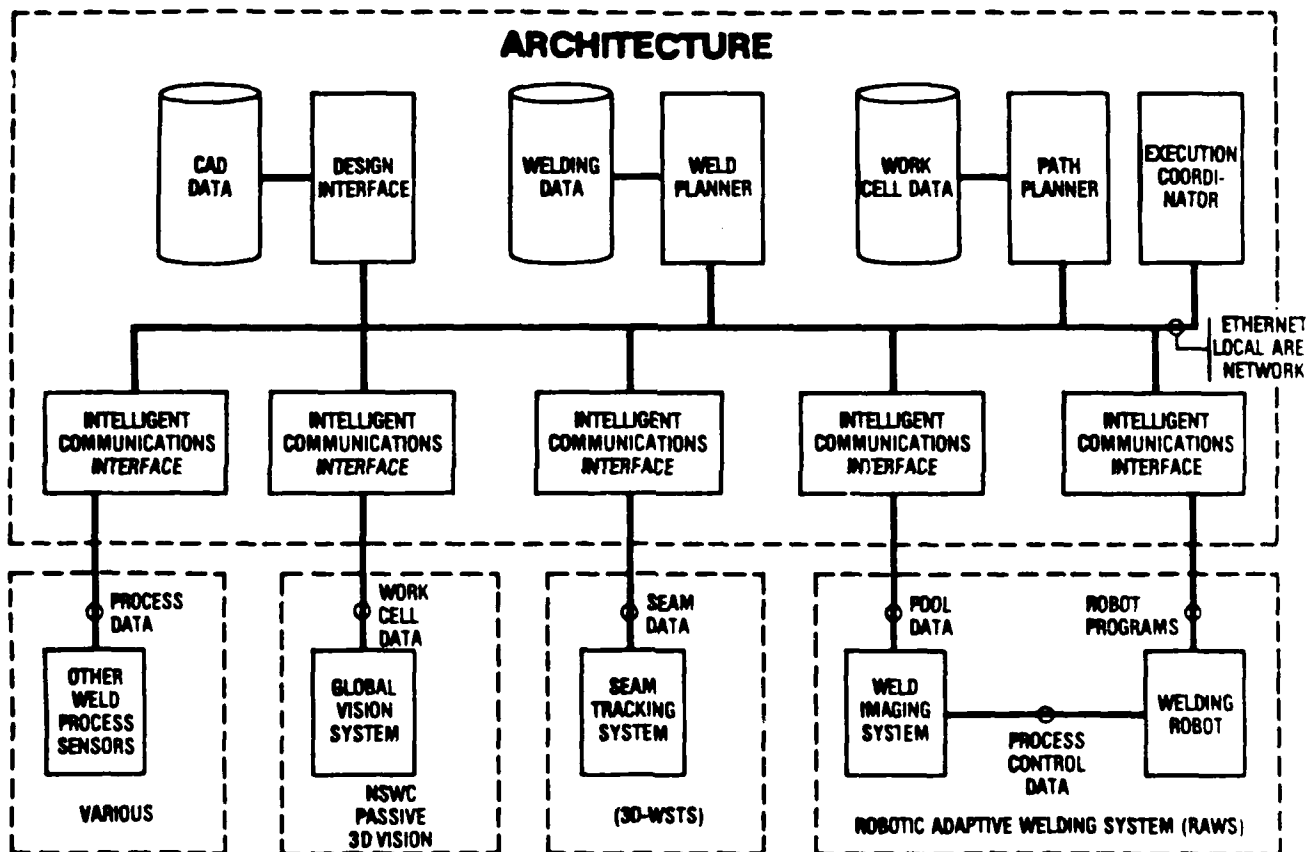
INTEGRATED FLEXIBLE WELDING SYSTEM

Figure 1. Architecture employed in the Integrated Flexible Welding System as proposed by the Naval Ocean Systems Center, San Diego, CA.

control hierarchy for interfacing with offline CAD datafiles describing part geometries, generating weld schedules, calculating robot motion trajectories, and providing for collision avoidance. All such planning is done in an offline mode by the rule-based experts, and the optimal program is then passed to the robot controller for execution with closed-loop feedback from the vision and process control sensors.

The highest tier of the IFWS, the knowledge-based planning and control components, permits the full utilization of the subsystems for goal achievement. These components include a Design Interface, a Weld Planner, a Path Planner, an Execution Coordinator, and Intelligent Communication Interfaces for each of the sensor and control subsystems.

The primary concept employed in the design of the IFWS computing structure is to partition the system to isolate specialized data and computationally-slow planning processes from the real-time sensor and control operations. Even the Execution Coordinator makes only tenuous connections with the real-time processes because it, for the most part, works in the future tense. The partitioning between offline planning and online functional processes is successful in this case because much is known for certain about the environment and task. Thus, it is relatively safe to plan much of the process offline through simulation (such as geometric modelling), since deviations from the simulation are expected to be small or nonexistent. This certainty is not uniformly distributed, however, and the Execution Coordinator must be reasonably powerful to recognize potential problems which may result, and

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develop corrections in the plans to anticipate these problems before they become uncontrollable.

The Design Interface is a computer-aided design work station through which the user will have access to the entire IFWS operation. It will enable the design and/or weld engineer to construct a solid model of the desired part and to represent the specifics of the weld process that are necessary for the workpiece model. This subsystem provides several levels of service to match the needs of the user. The Design Interface provides tools to enable the design engineer to interact with CAD databases, geometric modellers, and the application-specific expert systems. Through this interface, the part designer or welding engineer can build a geometric representation of the weldment and annotate it with welding information (e.g., weld seam location, desired weld strength and material specifications). The enhanced weldment representation can then be sent to the other planning processes in the IFWS. The Design Interface also provides an interface for shop floor personnel, providing access to the system for process monitoring, set-up operations, and maintenance. Finally, the Design Interface provides the systems programmers access to the internal data processing functions for system debugging and modification.

The Weld Planner takes the enhanced weldment design representation and from it and a body of expert welding knowledge constructs a welding plan. This plan consists of an ordered set of weld sequences associated with the various seams

to be welded. A group of process set points is associated with each weld pass. These parameters provide the initial settings for such values as arc current, travel speed, filler wire preheat, and wire feed rate. These parameters can be adjusted later by the adaptive control process.

The Weld Planner has been constructed using standard expert system development procedures. Several experts from different domains (e.g., welders, welding engineers, research engineers, and welding standards administrators) have been consulted in the formulation of a body of welding rules. These rules are embodied in a decision-tree structure which is processed during planning for each weldment. The expert system has been implemented using a computing environment which supports mixed representations. Some knowledge is encoded as LISP procedures, some as production rules, and some as data-driven actions. The Weld Planner structure has been formulated and exercised on several demonstration weldment designs with satisfactory results, and is now being expanded to handle a larger set of possible configurations.

The Path Planner examines the weld strategy geometric information to determine which of the options the workcell robot can execute without collisions. The Path Planner obtains the position and orientation of the workpiece in the workcell envelope from the global vision sensor. If possible, a complete movement plan is constructed and sent to the Execution Coordinator. The Path Planner takes the weld sequence input and tests the computer-generated movements in the workcell space

for possible collisions. It also constructs the manipulator actions necessary to move between weld passes without collisions.

This planner uses a database representing the geometry of the workcell configuration and several planning techniques to test and construct paths. In testing the safety of weld passes, the Path Planner uses a geometric modeller to determine the existence of potential collisions by simulating the robot's movements within the workcell. In planning the interpass movements, the planner proposes a gross movement sequence and generates a swept solid depiction representing that movement. This is then checked for interference with different parts of the workcell. If an interference is detected, then it is located and the path plan is incrementally modified until the interference is eliminated. This technique is reasonably efficient and can be used with both cartesian and articulated manipulators.

Once the end effector has been placed close to the beginning of the next weld pass, the fine motions of the robot are planned to bring the seam tracking sensor within range and view of the seam. This fine motion planning uses both a detailed representation of the end effector geometry and a "generate and test" procedure similar to that used in gross motion planning. This approach to path planning combines the benefits of well proven "generate and test" techniques with recent developments in computational geometry, suffering only slightly from degraded performance in favor of greater generality and simplicity. Fortunately, such planning occurs

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primarily offline from the actual welding procedure.

The Execution Coordinator takes the complete plan generated from the combined efforts of the Design Interface, the Weld Planner and the Path Planner, and disaggregates that plan into the parts that are transmitted to the sensing and control components of the IFWS. The Execution Coordinator also monitors the network traffic between the sensing and control components to determine the health of the plan. If the world state begins to deviate from the desired state and is outside the bounds of the adaptive controllers, then the Execution Coordinator makes incremental changes to the existing plan to bring the situation within the limits of control. If these attempts fail, then the Execution Coordinator stabilizes the situation (usually by stopping the weld process), and requests help from the offline planning processes in diagnosis and repair.

The present design of the Execution Coordinator employs a recently developed domain-independent planning engine and limited subsets of the Weld Planner and Path Planner databases. This planning engine has been designed to interface directly with the Intelligent Communication Interfaces in the IFWS. It can process sensor reports directly as it issues plans. The inference required for sensor data interpretation and plan generation uses an associative reasoning network. The nodes in the network represent workcell objects, plan goals, and robot actions, while the links represent the probability that two nodes in the network are related in time or space. This reasoning concept has been constructed and tested in a toy

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domain and work is proceeding to expand the supporting database.

Adaptive Weld Process Control

One of the primary supporting modules of the IFWS is the Robotic Adaptive Welding System (RAWS), a project managed by NAVSEA 070A. RAWS is being developed at the Westinghouse Research and Development Center under the Navy Manufacturing Technology Program, and is specifically aimed at the problems of small batch manufacturing. The initial RAWS system is built around an advanced GMAW welding torch mounted on a Unimate 6000 robot which is equipped with a Westinghouse weld pool vision sensor.

RAWS is intended to provide an enhanced GMAW welding capability, optimized for robotic implementation. The system's ability to maintain desired weld quality under varying conditions is achieved through the use of a weld pool imaging system and adaptive control strategies.

The weld process control feedback allows for consistent quality production welds when subassembly preparation and fit-up cannot be optimized, typically the case in shipyard environments. The characteristically unstructured conditions and low-volume lot sizes present several challenges requiring the innovative developments embodied in the RAWS project. The advanced gas metal arc welding process, developed by Westinghouse, utilizes an inline electrical preheat of filler wire, which helps to reduce the interdependence of arc voltage, current, stickout, and wire feed parameters during welding. Similarly, the Weld Pool Imaging System, which provides real time sensory feedback of the

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actual weldment characteristics, is a technological need dictated by the shipyard production environment. This optically based feedback sensor permits the adaptive change of process parameters in a real time manner, without operator intervention. The complexity of the envisioned workpiece geometries also mandated changes in the vendor's standard robot configuration. The unit's heavy duty wrist was replaced by a smaller substitute designed to access the restrictive enclosures common in Navy workpieces. RAWS will be ready for demonstration as an interim stand alone capability in the second quarter of FY 86.

Seam Tracking

Another important IFWS component, the Weld Seam Tracking System (WSTS), is also nearing Phase I completion. In order to provide single-pass, real-time guidance of the welding torch, the system looks a few inches ahead of the arc to gather three dimensional information on the workpiece geometry. Volumetric information about the weld gap also is used to provide an advanced input for weld process control.

The issue of weld seam tracking was identified early on as a technological need in support of an eventual shipyard robotic welding capability. In 1981, a contract was awarded to SRI International to develop a single pass, 3D weld seam tracking system for use in a shipyard environment. An existing prototype sensor designed by SRI was to be upgraded for this effort. This sensor operated by projecting a coded pattern of structured light onto the workpiece and interpreting the distortions to the image caused by intersection with the workpiece surface, as viewed by a

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two-dimensional camera a fixed distance away. The disadvantages of this type of approach arose from the long noise-integration time associated with reading the two-dimensional detector while operating in the presence of the weld arc, and the inability to deal with specular reflections caused by some workpiece surfaces.

An improved second generation sensor subsequently developed by SRI under an MT contract with the Navy collected three dimensional geometric information by projecting a collimated beam of light emitted by a laser diode onto the workpiece surface. The laser spot was mechanically scanned back and forth by a mirror to create a line of intersection with the workpiece, a function of distance to the target, and was detected by a 256 element linear diode array. The result was a markedly improved signal-to-noise ratio, relatively free of optical and electronic noise created by the arc.

The laboratory prototype seam tracker built by SRI was successfully demonstrated in 1983 welding on both aluminum and steel. A follow-on contract to harden the sensor for use in a production environment and to develop a very fast pipeline architecture to process the data was awarded in September 1984 to Robotic Vision Systems, Inc., with SRI International as a subcontractor. The end of project demonstration for this seam tracking system development, scheduled for the second quarter of FY 86, will illustrate the type of innovative developments that can result from the challenges presented by the Navy's unique shipbuilding needs.

Global Vision

An interim integration of the RAWS and WSTS efforts will yield an adaptive welding process incorporating a two-dimensional weld pool vision system and a three-dimensional seam tracking capability. The IFWS workcell, however, requires more autonomy to minimize the required programming and be of use to the Navy in low volume manufacturing and repair scenarios. In response to that need, the Global Vision System (GVS) was conceived as a sensor subsystem of the IFWS. The GVS is being developed by the Robotics Program Office of the Naval Surface Weapons Center (NSWC), White Oak, MD. The main components of the system are depicted functionally in Figure 2.

The objective of the GVS program is to develop a computer-based vision system employing special optical preprocessing and artificial intelligence (AI) techniques to achieve three dimensional, near-real-time machine vision. The system must be able to recognize and locate parts to be welded in the IFWS workcell to an accuracy of one half inch to assist in initial positioning of the robot arm and for purposes of collision avoidance. The GVS consists of two major components: the 3-D Vision Camera Subsystem and the Image Understanding Expert System.

The GVS provides the Path Planner and Weld Planner expert systems the necessary information regarding workcell geometry and part location. The GVS will enable the Path Planner to position the arm to acquire the part within the envelope of the torch mounted seam tracker, as well as to detect possible collision situations.
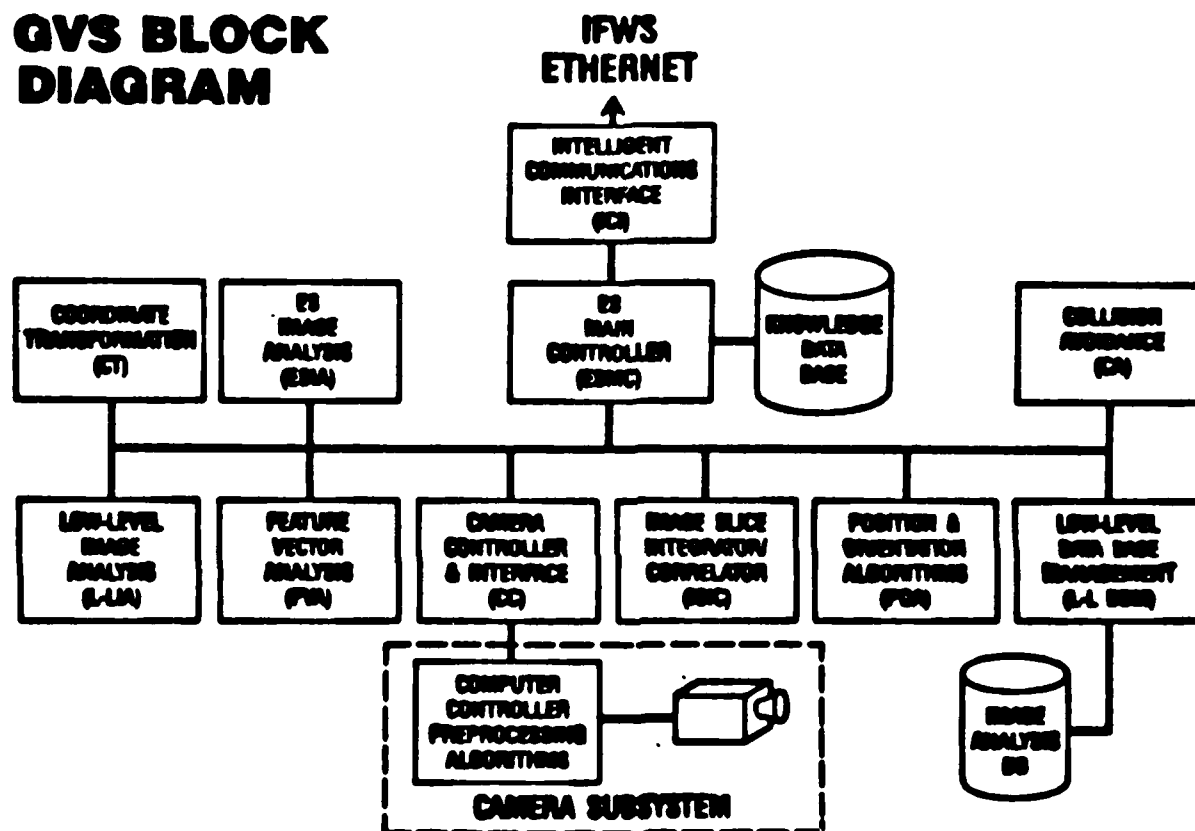
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Figure 2. Schematic representation of the Global Vision System as proposed by the Naval Surface Weapons Center, White Oak, MD.

The GVS will output the information in a symbolic format instead of large raw data transfers, communicating over the Ethernet bus via an Intelligent Communications Interface. The GVS will be given the part ID and will have access to the IFWS CAD database of part solid models, and will know the "world coordinates" of the work cell and its geometry. All processing will be done off-line when no actual welding is occurring.

3-D Camera Subsystem

Present-day 3-D imaging systems usually employ a stereo camera system with two cameras, special lighting and elaborate, time-consuming image processing. An alternate approach would be to use a laser rangefinder to scan the target, but this would be very time consuming and special lighting and processing are again required. For the IFWS, a very innovative approach developed by Associates and Ferren of Wainscott, NY, will be utilized to provide the global vision capability.

Work on the GVS camera subsystem was initiated in June 1983. The concept uses a servo-driven, very shallow depth-of-field scanning lens camera system to determine quickly the distance to various target features. Optical preprocessing is employed to achieve passive, 3D, real-time vision with sufficient field of view to cover the robot's working envelope. A prototype camera with special reconfigurable, wide-aperature optics employs a motorized lens focusing system to slew the focus back and forth throughout the range of interest to obtain a frame rate approaching 30 hertz.

The extremely shallow depth-of-field feature creates a

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series of 2-D image slices as the lens system is scanned, as shown in Figure 3. This enables reconstruction of a 2 & 1/2 dimensional representation of the target. The camera cannot see through an object; therefore, only the 3-D viewable portion can be reconstructed. The expert system, manipulating a CAD model of the part, will generate the entire 3-D image using rotation and template matching.

Much image processing, including feature extraction and clutter rejection, is performed instantaneously by glass optics and analog electronics to greatly reduce that required in later digital stages. Unwanted details (such as objects in the background) can be, in essence, filtered out simply by not allowing the system to focus on them.

The range resolution of the prototype is calculated to be the effective sensor depth of field divided by 1000. The reconfigurable nature of the optics allows for sweeping considerable distances with rather coarse resolution, and then readjusting the scanned range for high resolution data gathering in the local vicinity of a point of interest.

Image Understanding Expert System

The objective of the Image Understanding Expert System (IUES) is to control the 3-D camera system and evaluate the resulting images. By manipulating any a priori information and knowledge about expected conditions in the IFWS work cell, the system determines the part identity and location in accordance with the IFWS requirements.

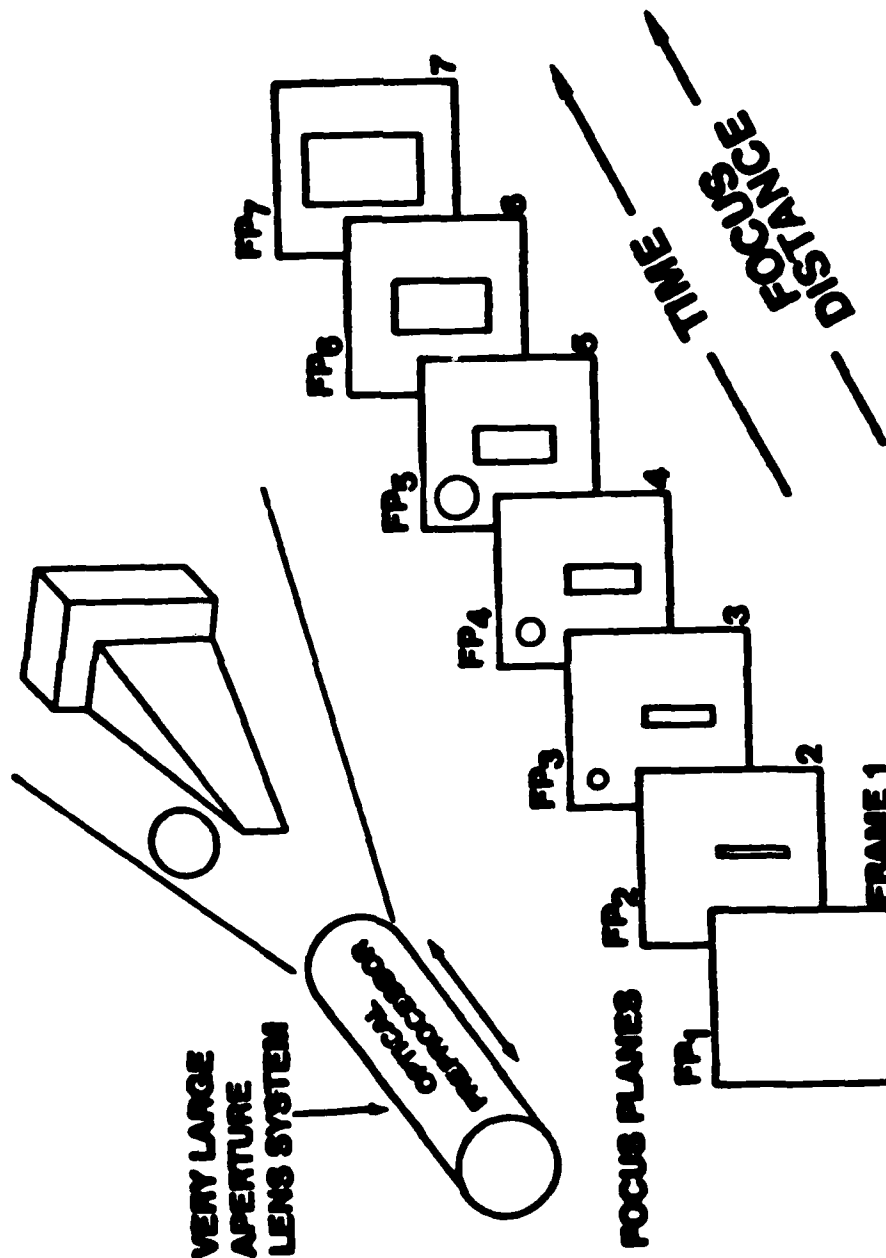The IUES is being developed on the Symbolics 3670 LISP

Figure 3. The scanning lens camera system creates successive two dimensional slices of the scene being viewed, which are then reconstructed to create a three dimensional model of the part.

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machine using LISP, the OPS5e Expert System development program, existing Fortran 77 image analysis routines, and low-level image analysis routines being developed under contract with the University of Cincinnati.

The Intelligent Communication Interface (ICI) will receive commands for the GVS from the NOSC Weld Planner and Path Planner. They will be placed on the ICI blackboard and will include the part ID and a request for position information. (The workpiece CAD model, along with all expected parts, will already reside in the GVS database. Provision can also be made to accept the model data along with the part identification.) The ICI will then direct the Main Controller to begin execution.

The Main Controller controls each module's operation or function and its parameters, schedules all tasks, executes and dynamically modifies the plan for reaching the goal of part location, and performs on-line GVS status checks. It selects the appropriate feature extraction algorithm to use, controls the correlation of the results of the low-level image analysis algorithms with the top-down ES analysis, and applies knowledge to modify the parameters of the low-level algorithms. In addition, the Main Controller directs the operation of the Camera Subsystem, determines which image slices to analyze, and what type of preprocessing is to be applied based on part knowledge and the analysis plan. If potential collision conditions exist, the IFWS is warned.

The Image Understanding Knowledge Database (KDB) contains all the information the system knows about images, the expected image components, the CAD models, the information about the

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components making up the expected parts to be welded, and all the system rules. The knowledge will be represented in the OPS5e rule and fact structure, except for the CAD models which will be maintained in a separate database.

The Camera Controller and Interface receives camera control commands and parameters from the Main Controller module and may reformat them for transmission to the camera subsystem computer and optical preprocessor. The parameters will indicate which filters to use, what maximum range to scan to, etc. The Camera Controller indicates what type of image data (raw video or edge detected) is being sent. The information is used by the Main Controller to decide what low-level image analysis routines are applicable to the part and its components. The ESIA analyzes the CAD model, determining the components of the workpiece. The ESIA may rotate and match components to the imagery to help determine orientation. It interacts with the Feature Analysis module to advise the Main Controller, (e.g., it asks for a close-up view of a component and for another analysis by a low-level image analysis routine to confirm a part identity.)

The Image Slice Integrator/Correlator builds a 3-D model of the part using the image slices from the camera subsystem, and coordinates with the Image Analysis module to compare results with the CAD model. It may also interact with the Low-Level Image Analysis module,and establish correlation among several image slices for ID or confidence level confirmation.

INTEGRATION PLAN

While the conceptual design and architecture for the IFWS was developed in a top-down manner, the integration of the actual componentry must occur in a bottom-up fashion. The evolution of the finished product will therefore be able to incorporate the technological growth required for the more sophisticated layers of the architecture as the building blocks of the IFWS (RAWS, WSTS, and GVS) are approaching completion. The integration of the components developed in a modular and independent fashion is thus a complex yet manageable task.

The reality of the situation is that not all applications will require the same supporting sensory modules and offline planning capabilities as envisioned and planned for the ultimate IFWS configuration. The task at hand becomes matching the required system capabilities to the needs of the user for each implementation. To support an assessment of this type, the Welding Applications Working Group of the NAVSEA Robotics Council was formed and tasked with conducting a survey of current shipyard practices. The various classes of welding applications will be ranked according to their level of difficulty and associated volume. At the same time, various combinations of IFWS components will be characterized to determine that class or classes of parts that a specific configuration could address. For example, certain simple classes of parts would, if produced in sufficient volume, require only the standard robot, controller, and teach pendant. At the other end of the spectrum, the extremely low volume and geometrically complex classes of

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parts will require the full autonomy projected for the IFWS.

As stated previously, RAWS and the laser-based seam tracker (WSTS) have separately scheduled end-of-project demonstrations. The Intelligent Communications Interface has been tested successfully in a laboratory environment at NOSC and awaits the opportunity to be integrated with lower-level IFWS components. Such a test will be performed in FY 86 using RAWS and the seam tracking system following the initial integration of those respective efforts. The knowledge-based systems and the GVS will be woven into the IFWS fabric as they near completion. The independent success of the system components, and their subsequent integration, are the milestones which will lead to the achievement and implementation of the IFWS.

SUMMARY

The Integrated Flexible Welding System represents a novel attempt to try to identify early on the ultimate goals for a complex robotic undertaking of interest to many of the functional codes within NAVSEA, and then to develop an evolutionary strategy for attaining these goals in a coordinated fashion. The issue of recognizing and following the seam to be welded is treated in the WSTS project which builds upon the earlier R&D work performed by SRI, International. The RAWS portion of the IFWS project specifically addresses optimizing the GMAW welding process to exploit the advantages of robotic implementation, and adding the appropriate sensor feedback to adaptively control the actual welding operation.

The real impact of this multi-player endeavor from the Navy's

perspective, however, will arise from the integration of some of these supportive subsystems through the rule-based expert systems being built at NOSC. It is through this approach that the required system intelligence is imparted which will ultimately allow a robotic welding workcell to perform in an efficient and practical fashion in a shipyard welding environment.

The modular approach has fostered the development of the Intelligent Communications Interface concept, which offers the Navy a clear opportunity to achieve some form of standardization, and drastically minimizes the chances of a multi-year development being obsolete shortly after completion.

From the perspective of the NAVSEA Robotics Program, the IFWS project pursues a valid and very meaningful objective that, when satisfied, will have much to contribute in terms of improved productivity and increased reliability not only in the construction of the last of the ships to be built for the 600 Ship Navy, but particularly in their repair over the many years of the projected life cycle for the modern fleet. With the availability of required funding as well as clear top-down direction and responsive coordinated performance by all participants, the development, testing, and implementation of the IFWS can be completed within the next three years, with measurable interim accomplishments that can be put to effective use.

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